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Original research article

Social acceptance of distributed energy systems in Swiss, German, and Austrian energy transitions

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ABSTRACT

Distributed energy systems (DESs) on a local scale constitute a promising niche to leverage renewable energy provision. These DESs (e.g., micro-cogeneration, multi-energy hubs) integrate renewable sources, combined heat and power production, various methods of energy conversion and storage, and active demand-side management. Since the broader uptake of such systems is still at an early stage, research about the adoption potentials of DESs in existing neighborhood contexts is scarce. Given their potential to contribute to energy transitions, it is relevant to gain a better understanding of the conditions under which these systems are diffused. Based on a quantitative study, we investigated the perceived responsibilities and the intended technology uptake of DESs among different societal groups in Switzerland, Germany, and Austria. We analyzed a sample of 2104 survey participants who were exposed to ranking tasks and a framing experiment and were asked questions about both opportunities and challenges in implementing DESs. Our results show an openness to engage with DESs; on average, the opportunities in applying DESs are rated higher than the challenges. However, in all three countries, the participants place the responsibility for the energy system transitions on the national government and large energy supply utilities. Municipalities and households are not yet considered relevant innovators. Moreover, the support of DESs is found to be independent from framing the DES implementation in relation to different scales of rationale (global climate change, national energy independence, or local autarky). Our findings illustrate not only the agents' attitudes toward DESs but also the structural path dependencies involving the implementation of distributed energy technologies. Our study implies the need to address the willingness to invest in new distributed energy infrastructures at the household level in the future. We discuss the necessity of identifying barriers to and drivers of technology applications ex-ante.

1. Introduction

Renewable energy-based distributed energy systems (DESs[1]) offer a socio-technical innovation that may contribute on a local (i.e., neighborhood) scale to achieving the carbon dioxide (CO_2) reduction aims of many countries [1,2]. For instance, Switzerland has developed the Federal Energy Strategy 2050 which defines ambitious energy efficiency and renewable targets for 2035 is guided by the ambitious long-term climate goal of reducing CO_2 emissions per capita to 1.0–1.5 tons by 2050 [3]. Germany aims to reduce its greenhouse gas emissions by at least 55% by 2030 compared with the 1990 emission levels[2], and Austria aims at a further downward trend which has been visible in recent years [4].

The functions of converting and storing intermittent electricity from solar and wind power generation or other technologies in either batteries (for the short term) or gas grids (for the long term) offer flexible and scalable forms of operating concepts. At the same time, early DES implementations demonstrate the potential for facilitating social innovations by triggering more decentralized models of ownership and operations that involve multiple agents [5,6]. However, not much is known about the acceptance of such facilities in urbanized areas. Accordingly, this paper's main research aim is to provide a better understanding of the potential of DESs by investigating the conditions for the social acceptance of such technology.

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[1] We call these systems DESs, while being aware that this acronym is also used in other contexts (see, e.g., ([93]) and stands for other terms, such as *distributed energy solutions*.

[2] https://www.umweltbundesamt.de/en/indicator-greenhouse-gas-emissions#textpart-1

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One focal area of studying the adoption of new socio-technical configurations such as DESs is their acceptance by different societal agents (e.g., [7–9]). The existing literature covers the acceptance of various renewable energy technologies, such as wind turbines or photovoltaic (PV) installations. However, a DES resembles a complex, integrated system of technologies rather than a single technology, such as a wind turbine or a biogas facility. With the concept of a DES as an attitudinal object, which facilitates the emergence of attitudinal responses, it is not an easy-to-grasp artifact compared with a single, clearly defined and visible infrastructure such as a wind mill, for which a number of acceptance studies exist [10,11]. An attitudinal object is a psychological object [12] that can be a concrete entity (e.g., a car or a computer) but also a non-material concept (e.g., homosexuality) or behavior (e.g., fast driving, smoking). The acceptance of DESs is therefore related to more than the agents' judgments about one of the integrated components or the sum of their single acceptance ratings. Instead, several levels of acceptance can in fact be distinguished for DESs [13]. Besides the socio-political level of acceptance, community and market acceptance also play a key role [9]. DES projects require recognition and uptake by potential investors, operators, users, as well as land and property owners. In this context, technological, economic, and social acceptance questions remain to be answered before a broad market adoption can evolve [14].

Although DES implementations have increased in number across various countries, they still constitute a niche for development in the existing centralized energy regimes [13]. Compared with the number of studies about public acceptance of single technologies, the recognition of DESs by the broader public (whether tenants or homeowners) remains unclear despite its relevance for further diffusion [15]. We thus talk about a socio-technical niche [16] which comprises a variety of sectors and actors.

In this study, we are particularly interested in citizens' attitudes toward a DES and whether they intend to promote and are willing to invest in such a system. Such intended engagement is coined with the concept of *active acceptance* and delivers insights into the active uptake of DESs in new forms of co-ownership as well [17].

Informed by an earlier review of the acceptance literature [13] in the DES context, we consider potential framing effects from public discourses that may affect DES acceptance [18]. Previous research suggests that promoting local benefits and co-ownership [7,14] elicits more positive attitudes toward participation in an energy infrastructure compared with framing its implementation with contributions to global climate change mitigation. Framing effects have been shown as influential factors in various contexts in the energy sector [19,20].

The adoption of a new socio-technical configuration such as a DES can be understood as a development in the long-term context of fundamental structural changes in the energy sector. It is commonly argued that technological innovation alone or system optimization in the energy sector is insufficient [21] to provide the full potential of decarbonization and energy demand reduction; thus, socio-technical innovations that affect markets, practices, cultures, and policies are necessary ([16]; B [5].). Such deep transformative changes (also referred to as *transitions*) require currently entrenched socio-technical configurations (e.g., as part of the existing energy regimes) to be de-institutionalized, as well as new ones, emerging from niche developments, to be created and diffused (e.g., DESs). Understanding not only the barriers but also the drivers and the promising pathways of such transition processes in the energy sector is a flourishing line of research [22]. However, societal acceptance of a socio-technical niche such as that occupied by DESs has not been investigated to date.

We have organized the rest of this article as follows. First, we describe DESs and exemplify them with the *energy hub* concept [23,24]. We then proceed with a theoretical underpinning of DES acceptance that draws on the transition theory in order to conceptualize a set of DESs (multi-energy hubs in particular) as a socio-technical niche emerging from multi-level transition dynamics [25,26]. Next, we present the methodology and the results of a large-scale survey conducted in the German-speaking part of Switzerland, as well as in Germany and Austria. Finally, we discuss our findings in the light of the evolving energy transitions in these countries and offer our outlook on future research options and policy implications.

2. Theoretical underpinnings of agency in energy transitions

2.1. DESs are niches of the current regime which is undergoing a transition

The emerging forms of energy supply and consumption to mitigate greenhouse gas emissions call for deep structural transitions to new, more sustainable energy practices. However, the occurring "challenges are coupled with and aggravated by the strong path-dependencies and lock-ins […]. Established technologies are highly intertwined with user practices and life styles, complementary technologies, business models, value chains, organizational structures, regulations, institutional structures, and even political structures" ([27], p. 955). In contrast, niches have emerged, which operate distributed and smaller, single-production capacities. However, as the illustration of a DES shows, incumbent agents may well play a key role in the transition of existing technology by collaborating with other agents [28]. Both "emerging and existing technologies are typically interrelated with other technologies – next to organizations and institutional structures" ([29], p. 2). The few existing DESs are currently operated to test their economic and technological feasibility [30,31] (with a growing number of pilot sites; see, e.g., the INVADE project in Germany and other countries[3]).

2.2. How niches are nurtured and shielded is important for understanding transitions and there are differences depending on how many agents are involved

In the transition theory, a relevant question then is how a niche may be nurtured and shielded to be developed and to gain a substantial foothold in markets, user practices, and regulations [32,33]. Early niche innovations have been dealt with conceptually by Verbong and Geels [26], who have analyzed the multiple levels involved in the historical emergence of the Dutch electricity system. In their study, they have found certain deployment models (e.g., co-owned community energy projects) facing additional implementation barriers due to the diversity of the involved agents and interests on a local scale. For instance, local, distributed energy generation that entails access to several homeowners' premises may require additional trust among the involved community agents [34].

2.3. DESs are particularly different as regime actors are part of the niche and collaborate with niche actors

The early transition literature purports the notion that the regime agents concentrate on incremental changes and try to avoid disruptive developments [35,36], which would pave the way for overcoming path dependencies. For this reason, established socio-technical systems usually undergo incremental rather than disruptive changes [37]. In the energy sector, we observe traditional incumbents, who continue focusing on the centralized production of fossil fuel-based energy from large power plants, as well as their progressive counterparts, who invest in renewable sources and more decentralized system solutions [16,38]. For the above reasons, *DESs differ from single-technology niches* and we propose the term "socio-technical niche" to be applied to them [39].

In the remainder of the paper we highlight some special features of DES and their potential role in energy transitions in three countries, Germany, Austria, and Switzerland, in a Background chapter. Here we also introduce the theoretical underpinnings used in this paper. Then

[3] https://h2020invade.eu/the-project/germany, retrieved 16 January 2019

the methods are explained with a focus on the questionnaire and its experimental design. After we present the survey results we turn to a discussion of the findings, in the light of current streams in transition literature. We close the paper with a conclusion section.

3. Background

3.1. Energy transitions in German-speaking European countries

In Europe, different strategies are adopted by different countries to decarbonize the energy sector and reduce the domestic energy demand. These envisaged energy system transitions are intended to be achieved by means of different measures at various levels. Our study included the three German-speaking countries—Germany, Austria, and Switzerland—but focused on the Swiss case. Accordingly, the German and the Austrian study samples mainly served to provide a comparison and better judgment of the Swiss results. Also, for this reason we restricted our study to a German speaking sample. In fact, the non-German parts of Switzerland are culturally different and results would have been difficult to interpret without adding elaborate cultural aspects to the study.

Switzerland targets 50% reduction in greenhouse gas emissions by 2030.[4] Switzerland has a high share of renewable electricity production (approximately 60% in 2016), stemming mainly from the established hydro power production,[5] while new installations are evolving slower (approximately 5%) [40]. The renewable sources' total share of the final energy demand was 22% in 2016. The long-term transition of the Swiss energy sector follows the Federal Energy Strategy 2050, which includes the stepwise phase-out of the domestic nuclear energy production, similar to the decision made in Germany. In the context of the Federal Energy Strategy 2050, several revisions of national energy laws have already been ratified and enforced, mostly aiming at enhancing the potentials for increased energy efficiencies and increasing the share of the renewable energy supply ([41], p. 99ff.).

In the National Climate Protection Plan 2050[6] adopted by the German government in November 2016, the reduction of German greenhouse gas emissions is a binding target. Additionally, in accordance with the Paris Agreement, a reduction in emissions of 55% by 2030 and 70% by 2040 should be achieved in Germany. The German public is well aware of the necessity to transform the current energy system. For example, a recent representative survey (July 2017) shows a very high rate (95%) of public acceptance of renewable energy production [42]. Moreover, 35% of the renewable energy technologies in Germany are in the hands of private owners.[7] Recent branch reports show that renewable sources contribute 36%[8] to the overall primary electricity production in Germany, and decentralization plays an increasingly important role in the German energy system. One of the key instruments governing the German energy transition is the Renewable Energy Act, which was recently amended in 2017. The regulations include feed-in tariffs for producers of renewable energy, which was recently modified toward a more flexible, market-driven compensation mechanism. Despite the substantial increase in the share of renewable energy production over the last decade, the implementation of DESs and integrated systems alike remains a scarce niche.

The third example, Austria, finds itself amid an accelerating transition of its energy sector in response to the EU-2020 target and following the Climate and Energy Directive from 2009. The directive's aim was to develop a roadmap to cut GHG-emissions by 21% and 16% in the ETS and non-ETS sectors until 2020 [43]. Since 2002, Austria has had a feed-in tariff in effect, complemented by federal funding schemes for investments in renewable energy production. In 2012, the Austrian Parliament ratified the revised law on green electricity, including explicit targets for the share of electricity from renewable sources in 2020 and additional funding schemes for investments in PV, wind, small-scale hydro, and biomass production. Recent data (2016) shows a 33% share of renewable sources in the final energy consumption in Austria.[9] Moreover, "the government aims to give energy a stronger role within its strategy on research, technology and innovation," stressing the "integration of renewable energy sources in the broader energy system (smart grids, storage technologies)" ([4], p. 22).

3.2. DES concepts

In this study, we follow Alanne and Saari's [44] broad definition, describing DESs as units that convert and store energy and are located close to energy consumers. These technologies shall help compensate for inter-day and seasonal fluctuations within the network, originating from the intermittent availability of some renewable energy sources, such as wind and PV installations. Moreover, DESs tend to help improve the energy system's efficiency and flexibility.

A DES application may comprise renewable energy sources, such as PV cells, solar thermal collectors, hybrid collectors, or wind turbines for local power generation (i.e., building integrated), that are combined with local- and regional-scale distribution technologies. Identified by different terms, these technologies often include local capabilities for power storage and conversion (e.g., batteries and power-to-gas conversion) [45], micro-cogeneration systems (e.g. [46,47],), and the distributed generation within smart grids (e.g [14]).

Ackermann et al. [48] argue that DESs may differ according to their "purpose, the location, the power scale, the power delivery, the technology, the environmental impact, the mode of operation, the ownership, and the penetration of distributed generation" (p. 196). Thus, different types of DESs exist. Among these types, an energy hub [45,49] can be considered a "distributed multi-generation energy system" [comprising] "functional units where multiple energy carriers are converted, stored, and dissipated" ([50], p.98). An energy hub may range from an individual building to a city quarter, a neighborhood, or an entire city [45].

However, existing DESs (in our case, the so-called multi-energy hubs; see Fig. 1 for a generic illustration) still represent the exception rather than the rule. The process of operating integrated systems poses specific challenges concerning the components' planning, implementation, coordination, and control [51,52]. Moreover, as DES represents a socio-technical niche, its adoption requires the acceptance of changes at multiple levels (e.g., technical, ownership, interdependence between consumers, etc.) not simply solutions for technological challenges.

3.3. DES demonstration projects

In this section, we cite examples of the few DES demonstration and early implementation projects in the three countries. An example of a DES in Switzerland has been implemented in the city of Solothurn by the regional energy utility.[10] This utility has established an energy hub to gain experience in DES operations and to conduct feasibility studies.

[4] https://www.admin.ch/gov/en/start/dokumentation/medienmitteilungen.msg-id-56394.html

[5] The energy share in the final energy consumption was 23.4% ([40]).

[6] Deutsche Bundesregierung (2016): Klimaschutzplan 2050; https://www.bmu.de/publikation/klimaschutzplan-2050

[7] https://www.unendlich-viel-energie.de/media-library/charts-and-data/renewable-energy-in-the-hands-of-the-people

[8] https://www.agora-energiewende.de/en/projects/-agothem-/Projekt/projektdetail/179/Jahresauswertung+2017/

[9] https://www.bmnt.gv.at/english/environment/energytransition/New-Publication-of–Renewable-Energy-2017–Database-2016—of-the-Austrian-Ministry-of-sustainability-and-Tourism.html; http://webstore.iea.org/energy-policies-of-iea-countries-austria-2014-review, retrieved 16 January 2019

[10] https://www.regioenergie.ch/

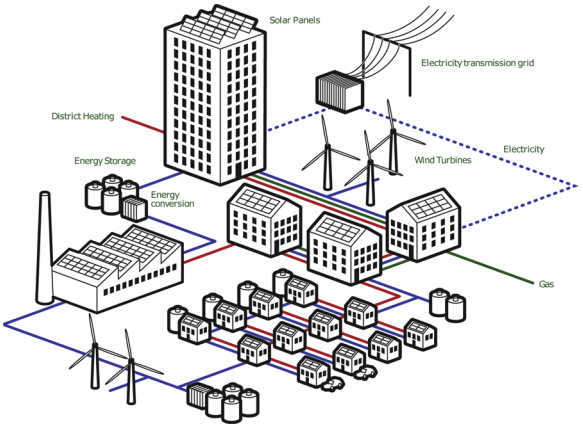

Fig. 1. Schematic illustration of an energy hub as an example of a DES. Such a DES can be operated both on-grid and off-grid (in relation to the existing grid systems).

Among other factors, the grid convergence and the single ownership of the necessary networks (electricity, heat, and gas) for converting the electricity produced by PV cells into gas have been relevant for the DES implementation on this location. The Swiss Federal Laboratories for Materials Science and Technology (Empa) operates a building in Dübendorf (Canton Zurich) as a living laboratory called NEST,[11] a new building concept to help launch innovative technologies and products (from the building and energy sector) on the market (quicker market readiness). On this site, Empa operates an energy hub as a DES.

In Germany, LichtBlick SE[12] offers a power system called a home power station, comprising a small-scale, combined heat and power plant (CHP). Several CHPs are linked by an intelligent information technology structure and operated as an integrated DES system. Moreover, software for microgrids is being developed, such as the Advanced Microgrid Optimization (AMIGO) by RTSoft in Ismaning, Germany.[13]

Likewise, in Austria, the energy system transition has been propelled by several initiatives. For instance, the E5 initiative in Vorarlberg[14] fosters regional energy production using renewable sources. Moreover, in Vienna the Aspern Smart City approach[15] is investigating how CO_2 emissions can be reduced and at the same time supply security maintained. The main challenge addressed is that an increasing number of decentralized energy producers and prosumers have to be integrated by using new storage technologies.

However, all these currently offered solutions are still at an early stage of development or implementation and operate on a small scale. The current pilot and demonstration projects in Switzerland are challenged with the issue of identifying feasible DES business models [53]. Moreover, socio-political acceptance and niche development are not yet known and are difficult to predict. The acceptance conditions of the socio-technical niche represented by DES remains largely unknown. This hinders not only the identification of feasible business models for DESs but also the resolution of public concerns and a successful framing for accelerating the energy transition. Surveying the public is therefore necessary at this early stage to gauge the best way to address public concerns and potentially successful framings for the transition. The technology may be on the market, but it has to be accepted socially, economically, and politically.

4. Methods: Survey on acceptance of a generic DES

4.1. Variables and hypotheses

In this section, we broadly describe the themes considered in the questionnaire, which are then explained in more detail in the following Questionnaire section.

Given the theoretical potential for decentralized ownership and broader adoption of DESs, we gauge the citizens' acceptance and willingness to become active participants in the course of the energy transition. Regarding the agency involved in the energy transition, we address the different societal agents' responsibility for taking action in the process of substantial changes in the energy sector. Previous research suggests the larger population's potential to become active agents of the energy transition, for example, in applying the concept of the *prosumer* (the combination of consumer and producer) [22,54]. As prosumers, citizens do not only consume energy but also produce it, for instance, via PV cells on their houses' roofs. As producers who earn some revenue for their added electricity, they usually have their home-based installations connected to the existing grid. Accordingly, our survey included questions on agency and the specific roles of individual households as prospective active partners in a DES. Specifically, we formulated one item on the degree of responsibility and activity for the energy transition, attributed by the respondents to several agents (e.g., energy utilities). We had no directed hypothesis on how the responsible respondents would rate the various agents. We expected that they would not rate themselves as highly responsible, though.

Moreover, promoting renewable energy projects' local benefits plays an important role in their acceptance, as noted in earlier studies [55]. Based on these findings, we hypothesized that in the case of a DES, its acceptance might be influenced by the scale of its implementation and the perceived spatial proximity and relatedness to the agents' local context [55,56], although different levels of place attachment may play a role [8]. We assumed the DES acceptance to be higher when presented in a local context versus being framed in a global or a national context [57]. In some countries (e.g., Switzerland), the principle of energy independence (autarky at the national level) is particularly relevant to the public, appreciated at several levels, and even assumed to increase energy security [58]. Moreover, from our literature review [13], we have learned that the acceptance of the infrastructure for renewable energy production in general and potentially for a DES is influenced by the amount of local benefits, whether in economic, environmental, or social terms [55,59,60]. The assumption is that the framing message activates mental images and links to attitudes that are important to the participants. We would thus expect active acceptance to be relatively highest under the local framing condition. To measure active acceptance, we used the scale developed by Schweizer-Ries [61] and Zoellner et al. [62].

We measured the respondents' general attitude toward a DES with two scales of items, illustrating potential risks and benefits, called *challenges and opportunities*. We developed these items based on our own experience from discussions with energy experts and the arguments mentioned in the acceptance literature. We expected the respondents to rate the challenges and the opportunities fairly similarly because there might be a generally positive attitude and some caveats.

We also measured the respondents' general attitude toward innovation based on Hurt, Joseph, and Cook's innovativeness scale [65]. Moreover, we wanted to control for the potential effects of knowledge about energy issues. Accordingly, we developed several items to measure the respondents' perceived own knowledge. From the authors' project context, questions about the potential future behavior of a DES member also emerged, which we implemented in the questionnaire as new items.

[11] https://www.empa.ch/web/nest/overview

[12] https://www.lichtblick.de/privatkunden/schwarm-energie

[13] http://rtsoft.de/products/platforms_for_customization/83, retrieved 16 January 2019

[14] https://www.energieinstitut.at, retrieved 16 January 2019: The more measures are implemented, the more "e" the community receives. From the third "e" onwards, the achievements are also awarded the European Energy Award®.

[15] https://www.ascr.at/en

4.2. Questionnaire

In this section, we present the questionnaire's structure and highlight the questions based on their descriptive results. The survey included questions (hereafter, items) on the general acceptance of a DES, its potential opportunities and challenges, a ranking task regarding the responsibility of agents, and a framing experiment emphasizing a global, a national, or a local context (plus a control condition).

For the data analysis, we used a mixed-method approach. We applied an analysis of variance (ANOVA, with a Bonferroni post-hoc test) to test for significant differences among the subsamples from the three countries. To identify the variables that explained the variance with respect to the dependent variable (*active acceptance*), we applied a linear regression analysis. The used item sets are described in the following subsections.

We conducted the study as an online survey among German-speaking Swiss (N = 1,056, homeowners = 42%, mean age = 46 years), as well as German (N = 531, homeowners = 53%, mean age = 46 years) and Austrian citizens (N = 517, homeowners = 50%, mean age = 43 years). Females comprised 50% of the recruited participants from each country. The sample was administered by respondi, an online access panel company (www.respondi.com), to ensure representativeness according to gender and the proportion of homeowners and tenants in the respective countries. There were no pertinent differences between men and women and between renters and homeowners concerning the included variables. Specifically, these subgroups did not show significantly different mean values; we do not include these results here but treat the sample as a whole.

4.3. Open question

Through an open question, we aimed to obtain the participants' general attitudes toward a DES. The DES was described with some text (see Box 1) and visualized with a figure (see Fig. 1) illustrating the concept to help the participants grasp an energy hub as an example of a DES. We asked, "What do you think of such an idea? Please write down briefly what you think about such integrated energy systems." The respondents could write their comments in a text box. A group of 1994 respondents provided meaningful answers. We deemed meaningful those answers that included at least one serious term, such as "good" or "clever," and of course, sentences such as "Good idea, as long as a sufficient energy supply for every household is guaranteed. Renewable energies should be promoted and increasingly used." We excluded all other text, such as "xxx" or "fgfgfdgdfg." The categorization was straightforward because the answers were fairly self-explanatory. Therefore, one person coded the answers as positive or negative, and another person further categorized them into groups.

4.4. Responsibility

For the Swiss subsample, we measured the concept of *responsibility* with the item, "In your opinion, who is responsible for the implementation of the Swiss Energy Strategy 2050?" For the German and the Austrian subsamples, we replaced "the Swiss Energy Strategy 2050" with "the German energy transition" and "the Austrian energy transition", respectively. The respondents had to rank the order of the following eight agents: the Swiss Federal Office of Energy (the federal government in the German and the Austrian subsamples), energy utilities, municipalities, cantons/federal states, industry, small- and medium-sized enterprises (SMEs), private households, and real estate owners/homeowners.[16] From the participants' perspective, the most important agent should be placed on top, followed by the others in decreasing importance.

Furthermore, all of the following variables formed the quantitative part of the questionnaire, with items to be rated on a Likert response scale (from 1 = "not correct at all" to 5 = "fully correct").

4.5. Framing, with "active acceptance" as the dependent variable

With an experimental framing condition, we tested the hypothesis that the local context framing would result in a higher acceptance of a DES. The participants were presented with one of four vignettes, representing the following conditions: *global relevance of DES adoption* (implementing a DES as a measure to reduce CO_2 emissions, combat climate change, etc.), *national relevance, with a DES as an important element of the Swiss/German/Austrian energy transition* (focusing on the Swiss/German/Austrian national levels, respectively), *a local DES for the energy independence of municipalities* (stressing the local level), and *a control condition* (no specific level was stressed). The translated vignettes can be found in the supplementary material in Box S1. These vignettes were randomly presented; each participant received one only. In total, each vignette was shown with equal frequency. After each participant read his/her specific framing vignette, we included a set of items to verify whether the vignette was read and understood. We thereby used a framing enforcement question, as described in more detail by Scannell and Gifford [63]. Making the participants reflect on their understanding of the presented vignette content was meant to enforce the framing effect.

The dependent variable *active acceptance* was measured by a scale comprising six items (see Table 1). The scale had a very good internal consistency in all three countries (for the whole sample, Cronbach's α = 0.85).

To test for significant differences among the framings with respect to the acceptance scale (values in the last row of Table 1), we used ANOVA (Bonferroni for post-hoc multiple comparisons).

4.6. Opportunities and challenges

With two sets of items (forming two scales on the respective topics of opportunities and challenges), we addressed the question of the drivers of and the barriers to the active adoption of a DES. These items were illustrated by the DES concept (with Fig. 1 added as visualization).

Box 1

Generic description of an energy hub for the open question (Swiss example). Together with Fig. 1, it illustrates the DES concept of energy production, conversion, and consumption on a neighborhood scale (in the introduction section of the online questionnaire).

> The future supply of electricity and heat for Swiss buildings will include a higher proportion of renewable energy sources (according to the government's Federal Energy Strategy 2050). One way to organize the energy supply in the future is the use of local, distributed systems. These energy systems are the results of the technical connection across several buildings of a city or a municipality. In this combination of buildings, electricity and heat can be generated (e.g., by solar panels on the roofs), converted (e.g., with power-to-gas conversion), and stored (e.g., in batteries).

The scales' internal consistency is very good (Cronbach's α = 0.89) for the opportunities and good for the challenges (α = 0.68). For an interpretation of Cronbach's α values, see [64], p. 675).

[16] The actors were presented in random order.

Table 1
Individual items that measure the dependent variable, acceptance of a DES (an energy hub). Results shown for the whole sample.

Items: acceptance	*M*	*SD*
I would participate in an information event about the local, distributed energy system.	3.8	1.15
I plan to learn more about the local, distributed energy system.	3.5	1.08
I do not intend to actively deal with the issue of the local, distributed energy system in my neighborhood (reverse).	3.7	1.20
I would actively contribute to building the distributed energy system in my neighborhood.	3.2	1.16
I would consider participating in the local, distributed energy system if my neighbors do so.	3.5	1.13
I can imagine investing in parts of the local, distributed energy system.	3.0	1.22
Scale	*3.4*	*0.87*

Notes: The response scale ranges from 1 = "not correct at all" to 5 = "fully correct." $N = 2104$. M = mean, SD = standard deviation.

Table 2 shows the participants' ratings (from 1 to 5, with increasing support) of potential opportunities ($M = 3.6$, $SD = 0.82$) and challenges ($M = 3.2$, $SD = 0.68$) with respect to the future establishment of a DES. As expected, we find a significantly positive correlation with the acceptance scale ($r = 0.74$) for the opportunities and a negative correlation for the challenges ($r = -0.35$), respectively, both with $p < 0.001$.

4.7. Attitude toward innovation

In our literature review, we identified the general attitude toward innovation as a relevant, influencing co-variate in the acceptance of new socio-technical configurations. Our measurement of the attitude toward innovation was based on an adapted version of the innovativeness scale presented by Hurt et al. [65], applied by Agarwal and Prasad [66], and revalidated by Goldsmith [67]. Selected items from the original 20-item scale were reformulated according to our study focus and shortened to a 7-item scale, which proved its validity and high internal consistency in a pre-test. The attitude was measured on a 5-point response scale, ranging from 1 = "not correct at all" to 5 = "fully correct."

Table 3 lists the items by which we measured the participants' general attitude toward innovation. The scale has very good internal consistency, with Cronbach's $\alpha = 0.86$. A positive attitude toward innovations in general is positively correlated with active acceptance ($r = 0.30$, $p < 0.001$).

4.8. Knowledge

We also asked the participants regarding the degree of knowledge about a DES that they ascribed to themselves, as follows: "Please indicate your knowledge and experience about various aspects of energy issues." They had to rate these aspects on a 5-point response scale, ranging from 1 = "no knowledge" to 5 = "expert knowledge." The four topics were energy technology, energy system/distribution networks, energy economy/business models, and energy policy/legislation (see Table S1 in the supplementary material). We also calculated a scale from these items by using the mean value. The scale's internal consistency is very good (Cronbach's $\alpha = 0.91$). The participants' reported knowledge level about the energy topic is fairly low (see Table S1), which is understandable, considering the general population sample recruited for this study. Moreover, the participants are laypeople. Half of whom are tenants and might not be expected to be experienced in dealing with electricity contracts or exchanging heating systems in houses. Higher subjective knowledge about energy topics is positively correlated with active acceptance ($r = 0.30$, $p < 0.001$).

4.9. Potential behavior regarding a DES

Challenges can be expected with respect to potential behavior regarding an integrated energy system such as a DES. We assessed potential behavior (and its limits) by means of a set of items. The scale's internal consistency is very good (Cronbach's $\alpha = 0.85$). The items are shown in Table S2 in the supplementary material.

5. Survey results

In this section, we present the results based on the statistical analyses of the previously introduced items. First, we investigated the potential of the perceived responsibility for taking action on the DES in the course of the energy transition. We asked the participants to rank their perceived responsibility of the agents (including themselves as homeowners or tenants). Second, we asked about the general acceptance of a DES. Third, we assumed that the framing of the DES implementation narrative would play a role in the acceptance of such a system. Specifically, we would determine whether people would more actively seek to engage in the DES if its implementation was framed as a solution to global climate change, the national energy autarky, or the local energy issues.

5.1. Responsibility

The respondents note that the responsibility for managing the energy transition should be assumed at the national political level (the federal ministry, e.g., the Swiss Federal Office of Energy) and by the energy supply utilities. The least responsibility is attributed to SMEs, households, and municipalities, as well as landowners and property owners (see Fig. 2, which shows only the first four ranks). Although the majority of the respondents find the idea of a connected and distributed energy infrastructure appealing and would be willing to adopt it, many respondents also expect a top-down initiative for implementing new socio-technical configurations in the course of the energy transition. Here, we only show the results for Switzerland; those for the other two countries are similar in the ranking order. The national policy body and the energy utilities are top ranked as the responsible entities in all three countries.

5.2. Acceptance

Table 4 shows country differences in the dependent variable *active acceptance*. Notably, this variable is rated significantly higher by the Swiss participants than by their German counterparts, who show the lowest active acceptance on average. Correspondingly, they perceive more challenges than Swiss participants do. When we analyze the perceived opportunities ascribed to the DES adoption, all three countries show equal values. Therefore, the Germans perceive more challenges relative to opportunities and thus show lower acceptance. The Austrian participants rate the scales similarly to the Germans' rankings or in between those of the Germans and the Swiss.

The results illustrate the positive general attitude found in the replies to the open question (the details are not reported here due to space constraints, but see Table 5). The analysis of the responses to the *open question* shows the general desirability of the presented DES concept (a participant's comment could of course comprise both negative and positive statements, which are counted separately). The majority of the responses are positive ($N = 2039$, 68%). More details can be found in

Table 2
Participants' perceived opportunities and challenges concerning the establishment of a DES (energy hub) in their neighborhood. Results shown for the whole sample.

DES opportunities for me as an active member	*M*	*SD*	DES challenges for me as an active member	*M*	*SD*
I could ensure a better balance between the energy supply and demand in my building and neighborhood.	3.9	1.05	I have too little knowledge about local, distributed energy systems.	3.7	1.04
I would make my own contribution to the Swiss/German/Austrian energy system transition.	3.8	1.09	I would ask myself whether this would result in higher energy costs for me.	3.1	1.17
I would support a more distributed and thus more flexible energy supply.	3.7	1.07	I would ask myself if my power supply would still be secured.	3.1	1.17
As part of a local, distributed energy system, my energy supply would be more independent than it is currently.	3.4	1.01	The legal framework for renewable energy is too uncertain for me.	3.0	1.03
As a participant of a local, distributed energy system, I would be better linked to the other participants in my neighborhood.	3.4	1.01	I do not want to be dependent on the other participants of the local, distributed energy system.	2.9	1.17
Local, distributed energy systems are promising opportunities for investment.	3.4	1.07	I simply do not have time to engage in new energy technologies.	2.7	1.12
Scale of opportunities	*3.6*	*0.82*	*Scale of challenges*	*3.2*	*0.68*

Notes: The values in each column are ordered according to their mean values. *M* = mean, *SD* = standard deviation. *N* = 2104. The response scale ranges from 1 = "not correct at all" to 5 = "fully correct.".

Table 3
Individual items of the scale on the general attitude toward innovation. Results shown for the whole sample.

Items about attitude toward innovation	*M*	*SD*
In general, I am reluctant to try new technologies (reverse).	3.4	1.23
I like to try new technologies myself.	3.3	1.22
I react rather reservedly to new technologies (reverse).	3.3	1.21
I read articles about new technologies with great interest.	3.2	1.22
When I hear of a new technology, I want to test it myself as quickly as possible.	2.9	1.16
Among colleagues and friends, I am usually the first to test a new technology.	2.6	1.18
Scale	*3.1*	*0.90*

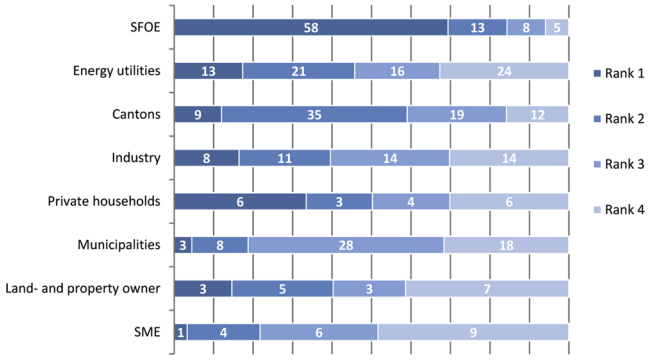

Fig. 2. Agents responsible for the energy system transition (based on the respondents' rankings).
Only the top four of the eight rankings by the Swiss subsample are shown as examples. The Swiss Federal Office of Energy (SFOE) is ranked first most often (58 times, first row), whereas small- and medium-sized enterprises (SMEs) occupy that position only once (bottom row).

Table 4
Country differences in active acceptance, perceived opportunities, and attitudes toward innovation.

Selected variables		Switzerland[a] (*N* = 1056)	Germany[b] (*N* = 531)	Austria[c] (*N* = 517)
Active acceptance	*M*	3.5[b]	3.3[a]	3.4
	SD	0.85	0.90	0.88
Opportunities	*M*	3.6	3.6	3.6
	SD	0.82	0.83	0.82
Challenges	*M*	3.1[b, c]	3.3[a]	3.3[a]
	SD	0.67	0.71	0.64
Attitude toward innovation	*M*	3.1	3.1	3.1
	SD	0.87	0.93	0.92

Notes: The response scale ranges from 1 = "not correct at all" to 5 = "fully correct." The superscripts indicate that the mean difference is significant at the 0.01 level.

Table 5
Responses to the open question. Positive, negative, and neutral refer to the respondents' general attitude toward the DES concepts.

Category	Frequency		
	Switzerland	Germany	Austria
Positive	1061	460	518
Negative	318	157	135
Neutral	178	62	84

Table S3 of the supplementary material. The participants also express their perceptions of the challenges and the open items (negative comments: 21%, neutral comments: 11%). The following examples illustrate the variety of the answers: "Everything that leads to a future

reduction of energy consumption is an advantage. In these interconnected systems, the infrastructure may be limited. This may mean less structural changes or landscape degradation." "Basically a good solution but will fail due to the autonomy of the Swiss." "I find it a little too far-fetched, that is, too difficult to implement."[17] The topics about the opportunities are the participants' (as producers) own contributions to the energy independence and the link to the other participants in the DES. For the challenges, the participants list their doubts regarding energy security, costs, and legal issues. The most prominent statements for both scales turn out to be the better balance between the energy supply and demand in the building and the neighborhood, while often acknowledging the current lack of knowledge.

When analyzing the independent variables' influence on active acceptance, different patterns can be observed for each country. Table 6 demonstrates that the acceptance of the DES is largely driven by the perceived opportunities, whereas the three variables, *general attitude toward innovations*, *knowledge about energy themes*, and *potential behavior toward DES participation*, explain only minor shares of variance (although partly statistically significant). The item "I have too little knowledge about energy network systems" is rated $M = 3.7$; $SD = 1.04$, which also reveals some degree of uncertainty among the respondents. Notably, there are no major correlations among the independent variables (see Table S4). The highest correlation is between opportunities and potential behavior ($r = 0.54$). Moreover, the variance inflation factor is in no case higher than 1.7, and the tolerance level is 0.599 at the maximum. These values all indicate fairly good regression conditions.

5.3. Framing

For the hypothesized influence of framing, the implementation rationale for the people's active acceptance of the DES shows ambiguous results. We could not identify a significant influence of the different framing conditions on the dependent variable *active acceptance* (see Fig. 3). The respondents are sensitive to the framing condition to which they are randomly assigned (i.e., the framing enforcement scale results in differences among the assigned framing groups; see the Methods section), but they do not rate the acceptance items with significant differences ($F_{3,1084} = 1.9$, $p = 0.126$). This finding holds true for all three countries (thus, we only present the result for the total sample). This result indicates that under the current early adoption conditions, at least on the aggregate, it makes no difference if a DES is framed in terms of addressing its implementation relevance to global climate change, the future of the national energy system, or the local DES benefits. Examining the opportunities and the challenges that are potentially linked with the technology provides a clearer picture of people's reasons for accepting or rejecting a DES. We further discuss our insights and the implications of this non-significant result in the Discussion section.

6. Discussion

In the current study about the acceptance of DES, the main objective was to provide a better understanding of the potential of these systems by investigating the conditions for their social acceptance. The particular research questions addressed the perceived responsibility for the energy transition attributed by the respondents to different agents (e.g., energy utilities or themselves); the DES's acceptance as potentially influenced by the perceived spatial proximity and relatedness to the agents' local context; the relative rating of opportunities and challenges of a DES in one's neighborhood.

The results show the participants' neutral to moderately positive attitudes toward a DES (here, a multi-energy hub) in general. The main drivers for acceptance are the potential energy-related benefits and each participant's positive contribution to the energy system transition. Moreover, the perceived opportunities offered by a DES adoption, a positive attitude toward innovations in general, and higher subjective knowledge about energy topics, are positively correlated with active acceptance. Interestingly, the open comments are more positive than the attitudes purported in the quantitative part of the survey. Our interpretation of the results is that for most participants, a DES in the best-case scenario may offer a convenient solution to future energy supply problems. At the same time, they express some concerns and point to important issues that have to be solved, such as legal issues and dependence on other households in the hub.

No significant framing effects are found in our study. Specifically, for our subsamples in Switzerland, Germany, and Austria, when rating the dependent variable, it does not matter if the vignette stresses the local, the national, or the global implications. The acceptance level is fairly similar under all conditions. This finding is surprising to some degree since the climate change frame is expected to have an effect because a DES may be perceived as a systemic response to climate change (as has been found for nuclear technology, [68]). From this perspective, climate change should have a more positive effect on acceptance than national energy autarky or local energy issues, which is not the case. In contrast, local topics are more proximate to the people's lives, which influenced our original hypothesis [56]. Therefore, perhaps the result emerges from the fact that different people are motivated more by one level and less by others, resulting on the aggregate in a tie. Concern about climate change has multiple roots [69]. Our research design does not account for a framing comparison within subjects but only between different subjects. Other explanations may be that the DES description provided at the start of the questionnaire is still too abstract, and the case is too hypothetical for most respondents. The attitudinal object may thus be too fuzzy, and more tangible imagery is necessary. Essentially, the issue of local versus national or global framing may become more important in a more concrete case, where a clear configuration of a DES can be presented in a realistic neighborhood context. Although the literature suggests the relevance of different framings, narratives, or discourses on acceptance, we do not find significant differences [20,70,71].

A recent study about investment decisions regarding innovative energy systems (Ecker et al. [72]) also reports no significant effects of their national versus local framing conditions (neighborhood or small town level). However, significant results emerge at the household level, where an energy autarky scenario leads to a higher willingness to invest compared with the other framing conditions. The authors argue that the participants account for anticipated problems regarding feasibility, communication among a higher number of agents in the neighborhood, and town framings, similar to our open responses. As the household level is excluded from our study, no final conclusions can be drawn about the potential effects of different framings in our sample. As conceptualized here, a household is part of a DES in a neighborhood, not autarkic with respect to a participant's building. To the participants, this may likely appear as increasing dependence, not independence. Further research on this issue is certainly advised [73].

There may be different options for implementing and operating a DES. Basically, a policymaking body could distinguish between community-based (and/or community-owned) energy systems, distributed with respect to energy production and operators, on one hand, and a DES operated by one agent (e.g., a supply utility as a regime insider), on the other hand [74]. Interestingly, a socio-technical niche such as the DES energy hub illustrated in our study is currently operated by established regime incumbents. One reason for this is that DESs are part of the regular research and development (R&D) investments of the current energy regime incumbents and their quest for new business models [75].

In other words, a socio-technical niche such as a DES in its current development phase may be an investigation field for incumbent agents

[17] Translated from German to English by the authors

Table 6
Results of a regression analysis for each country (dependent variable: active acceptance). See also supplementary Table S4.

	Switzerland (N = 1056)			Germany (N = 531)			Austria (N = 517)		
	B	SE B	β	B	SE B	β	B	SE B	β
(Constant)	0.80	0.15		0.40	0.19		1.10	0.24	
Attitude toward innovation	0.09	0.02	0.09**	0.04	0.03	0.04	0.00	0.03	0.00
Opportunities	0.58	0.03	0.56**	0.64	0.04	0.59**	0.66	0.04	0.61**
Challenges	−0.14	0.03	−0.11**	−0.09	0.04	−0.07*	−0.19	0.04	−0.14**
Knowledge	0.10	0.02	0.10**	0.15	0.03	0.15**	0.11	0.03	0.10*
Potential behavior toward energy hub	0.15	0.03	0.15**	0.17	0.03	0.17**	0.13	0.04	0.12*
	R^2 = 0.59			R^2 = 0.64			R^2 = 0.60		
	$^{**}p < 0.001$		$^{*}p < 0.05$						

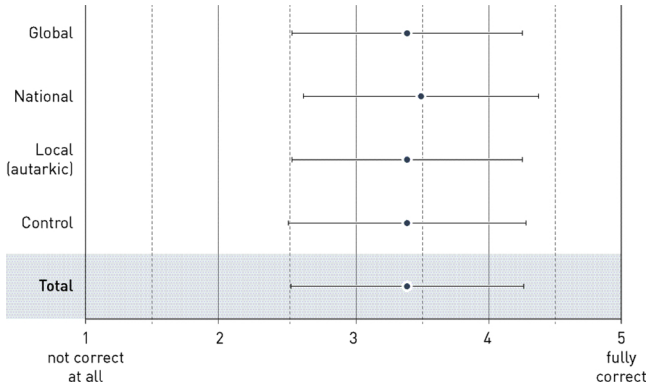

Fig. 3. Results for the dependent variable (acceptance) under each framing condition. There are only tendencies but no significant differences among the framing conditions (in each country).

but less so for cooperatives and (individual) grassroots agents. This view is in line with the findings of von Wirth et al. [13], who identify the current regime incumbents, such as local energy utilities and grid operators, as the active agents conducting tests and trials by using DES approaches in Switzerland, Germany, and Austria.

Given that DESs offer the option of distributed structures of ownership and operation, pilot projects are emerging, involving local agents, such as cooperatives or energy communities [54,55,60,76]. Moreover, there may be different approaches to such cooperative solutions with specific organizational challenges [77]. For example, the bio-energy village Jühnde[18] in Germany, which converted the village's energy supply from fossils to renewable sources, used a clear bottom-up approach [32]. For established single technologies, such as solar panels, less diverse knowledge and expertise are required, and those are relatively easy to install and operate. In contrast, DESs are often based on existing technologies, yet operators still need to accumulate experience concerning integrating various technologies and operating them in a connected way.

When referring to the dynamics between the socio-technical niche of DESs and the practices of the current regime incumbents (mainly the energy utilities and the grid operators), it becomes clear that the regime incumbents are testing the DESs' technical and financial feasibility and presenting the main agency in the context of further adoption of such systems. Interestingly, the survey participants appear to prefer this constellation. They designate the main responsibility for implementing the energy system transition to the national political level (e.g., the Swiss Federal Office of Energy) and the established energy supply utilities. The respondents also do not strongly perceive themselves as becoming active members of a DES (or becoming engaged in smart grids; see [78]). This perspective may be related to a certain pattern of accountability among the end users, which ascribes this responsibility to regulators or traditional energy infrastructure providers, even in the case of decentralized structures such as DESs; thus, the supposed change from a passive to an active role of acceptance has not yet been completed. The precise scope of the responsibility that individuals or local groups may assume remains unclear despite the general positive attitude toward the niche technology.

These findings illustrate that at present, DESs depend on the current regime agents and the existing energy infrastructure (e.g., the existing grid architecture for gas, heat, and electricity). Therefore, DESs per se are not necessarily disruptive innovations (see for instance, [79,80]), which also points to the lack of niche operators, at least partly due to several structural and regulatory reasons [13]. Nonetheless, there remains much (also political) hope that bottom-up initiatives and prosumers will play a significant role in the energy transition [30]. Without actively engaging homeowners and property owners and addressing their concerns, local initiatives may grow in number but still lack substantial impact.

We neither advocate for a purely decentralized energy system nor for one-way, local bottom-up approaches. However, if the idea of local bottom-up DESs should become a major part of the energy system, which is more than wishful thinking, meaningful participation efforts and appropriate business models for citizens must be developed.

An investment without a business model (see the latter part of this section) cannot easily be made by local agents, such as cooperatives [81]. A consistent and long-term policy to guide the implementation of the necessary facilities is needed [82]. DES acceleration needs federal, regime-oriented R&D vehicles rather than the current bottom-up/niche-funding structures. It could also imply that cross-technology, integrated funding schemes for research (e.g., including production, conversion, and storage), and usage from a coupled socio-technical perspective could be strengthened. However, the situation regarding funding schemes and incentives by means of policies is dynamic and far from clear in the three surveyed countries. Bottom-up developments must be based on the engagement of active citizens, stressing local values, participation, and ownership, as exemplified in the Jühnde project in Germany [32]. Regarding Germany's first village to produce heat and electricity by means of renewable biomass (Jühnde [83], no page), three key aspects for success in this field are mentioned: "1. A radical information policy through village-gatherings and info-letters, also mentioning the problems of this project. 2. Participation of villagers in workshops and working groups. 3. Competent persons in the village who [are] willing to provide information about this project at any time."

Thus, for a DES, at least equal efforts by local citizens should propel the technology diffusion. To help local initiatives, it should be demonstrated that local solutions are feasible in various contexts, and facilities can be operated by third-sector associations, such as cooperatives or other local or regional agents [54].

Given that citizens in general appear unprepared to adopt their new roles, for instance, as prosumers or other active agents in the energy

[18] http://www.bioenergiedorf.de/index.php?id=5&L=1

transition, the importance of so-called intermediaries may grow. A systematic review [87] shows different types of intermediaries. Not all of them may be sustainability oriented. Nevertheless, in the early stages of the transition, niche intermediaries in particular could connect different projects for various socio-technical configurations. The authors conclude that systemic and niche intermediaries are essential but need to be supplemented by other types, such as "regime-based transition intermediaries" and "user intermediaries." These kinds of intermediary agents could close the gap between technical solutions, business models, and citizens [84], empowering sustainable energy innovations [85].

Business models for DESs are only being developed at this time. Particularly, at their present state, pilot or demonstration facilities often exist without a durable business model in these facilities is often as well lacking [86]. Nevertheless, the development of business models at the early stages of DES diffusion appears central towards indicating how the DES implementation can actually emerge further, besides solving remaining technical challenges. [87], p. 805) stress that "business models for distributed energy generation are challenged by the huge uncertainty of demand."

In order to address these uncertainties and development risks, appropriate policy support should facilitate the emergence of such socio-technical niche technologies [88], for example in the form of conventional policy interventions, such as R&D investments or targeted subsidies, or by establishing innovative research – industry – society settings such as Urban Living Labs [89].

Governments have to design and implement appropriate policies and framework conditions to ensure the competitiveness of entrepreneurs establishing new business models for new technologies and services [53]. Currently, the established energy agents dominate the pilot installations of DESs, with rare involvement by other agents. In geographical contexts other than those included in our study, the engagement of agents may vary. For example, according to Lockyer [90], the engagement of local bottom-up initiatives, such as ecovillages and transition towns, is increasing. These initiatives have pioneered distributed renewable energy technologies, for instance, in the form of community-owned wind turbines and cooperatively managed micro-hydro systems, including a collective business model.

In addition to the preceding discussion about the abstract nature of the DES concept, which may limit the significance of the study, some further issues should be addressed here. For instance, we did not include the household level in our framing experiment. Thus, we cannot draw final conclusions about the influence of different framings on the acceptance of a DES, as indicated. In addition, this study did focus on the role of attitudes towards innovation and knowledge in their effect on active acceptance of DES. Future research could also test the influence of environmental awareness, which has been shown as a motivator for adoption for example of microgeneration energy technologies [91].

Moreover, our samples may not be representative of the general population in each of the three countries; thus, the conclusions may only be valid for the respondents. However, this is one of the general limitations that any survey may suffer because we cannot control for self-selection bias, irrespective of whether a directory, a population register, or an online panel-based survey is used. At any rate, the results seem plausible, particularly the outcome of the regression model. For example, it makes sense that those respondents who recognize the opportunities offered by the DES concept state higher active acceptance. Given the similar findings among the three countries, we may speculate that these attitudes toward early emerging technologies may be stable across national policy, energy system, and/or cultural boundaries. Further studies in other contexts and countries are needed to validate our study's results. Additional research is also required to clarify whether existing business models are (or the lack of them is) relevant for the social acceptance of DESs, as well as to delve deeper into the issue of various agents' responsibilities [92].

7. Conclusion and outlook

With this quantitative study about the acceptance of DESs, we have gained the initial insights into tenants' and homeowners' perceptions of a new decentralized renewable energy infrastructure, which may shift their roles from energy consumers to prosumers. This potential and partial role change poses socio-technical challenges because neither has the DES concept fully matured and proven its suitability in practice yet, nor is it clear what kinds of participatory and business-sharing schemes will emerge that may help unfold its potential.

Our study's main objective was to identify the active acceptance of DESs, such as multi-energy hubs, as means to foster the energy systems' transition. The survey administered in Switzerland, Germany, and Austria also aimed to determine which agents were attributed the main responsibility for the ongoing system transitions in the three countries. To understand whether different framing conditions for the implementation of a DES would have distinct effects on the citizens' acceptance, we included three framing vignettes and a control condition with no specific framing.

Our study sheds light on the social acceptance and the potential role of DESs in future energy systems. Examples of local energy systems have emerged, but the reasons for their success or failure are not always clear. Our study indicates a moderate acceptance of a DES, where the positive aspects are probably more about wishes or hopes for future energy systems. Currently, different framings appear not to have positive or negative influence on acceptance. More research about the potential influence of the three (or better yet, four) levels—the global challenge of climate change, the national efforts in the transition of energy systems to carbon-free alternatives, and the regional and the local scales (including the citizens' own detached houses)—is needed. These framings may trigger social participation and local social networks, as well as the willingness to financially invest in DES projects. Further, psychological research on energy science as such would also be necessary to acquire a better understanding of potential framing effects.

The participants (not only some active initiators) in such networks have to take on specific roles (e.g., as prosumers or hosts of the infrastructure), and the question is whether they are prepared and willing to do so. The proponents of technology-driven concepts may not reflect on this point too strongly. Our results at least suggest a potential mismatch between energy agents' and policymakers' expectations and consumers' expectations. In a more general sense, if DESs have to be operated by local initiatives, such as energy cooperatives or citizens' energy associations (which are currently starting to evolve), the notion of passive local-level agents and active national agents should be reflected on. The governance of energy has to prepare for and be open to niche developments, such as local DESs (including multi-energy hubs on a neighborhood scale), and the regime agents may actively invest in pilot facilities, which involve a fundamental change of roles. Demonstration projects should be jointly undertaken by cities and local agents (these could be called "collective distributed demonstration projects"). This approach is necessary to show the public how bottom-up processes can be developed. The question of how relevant agents (e.g., energy utilities, communities, large real estate investors, homeowners) may be open to implementing a local DES is crucial in the early market adoption phase. It is necessary to conduct further research, not only about the influence of different framing conditions on the public acceptance of new kinds of energy infrastructure, but also about the question of whether the public accepts new roles, such as prosumers, agents on the energy market, and others.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.erss.2019.04.006.

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